Mobility Research & Development

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Tank Automotive Research, Development and Engineering Center

Research, Development and Engineering Command

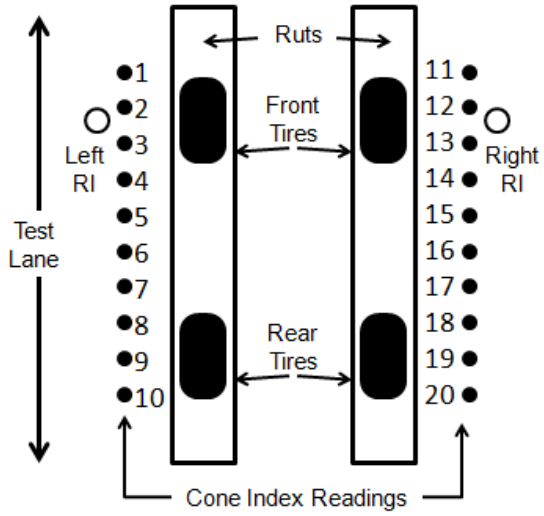
Army Materiel Command

United States Army

2016

Off-Road Mobility Challenges

Empirical Approach: NATO Reference Mobility Model

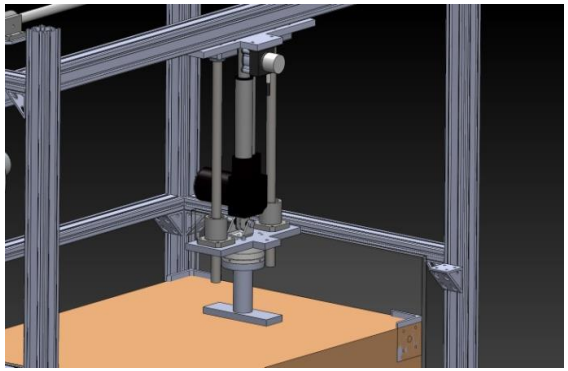


NATO Reference Mobility Model (NRMM)

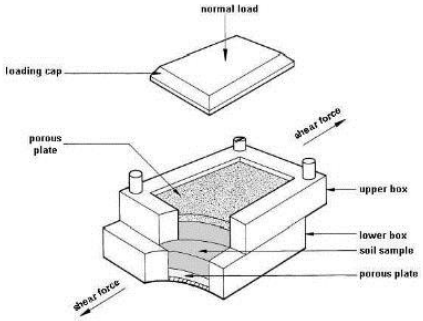
- Dr. M. G. Bekker of TARDEC is the "Father of Terrain-Vehicle Systems"
- NRMM was developed in 1960-70 by TARDEC and ERDC
- Accepted as a NATO standard in 1977-78
- Methodology relied on empirical relationships and **not** physics-based
- Does **not** extrapolate to contemporary vehicle designs and technologies
- Does **not** benefit from advances in simulation and computational capabilities

Building Blocks: Scaled Experiments

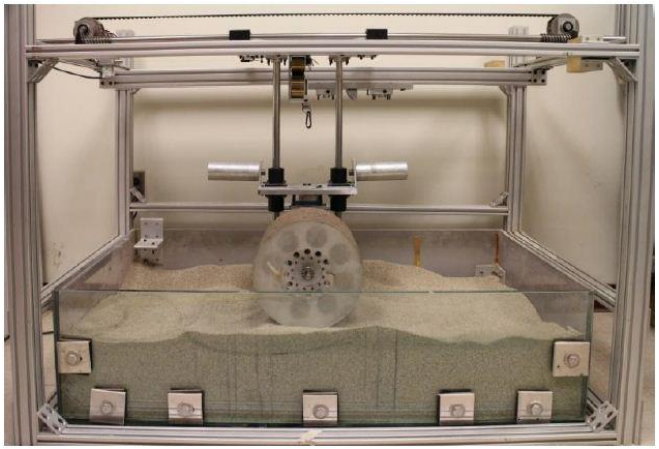
Pressure – Sinkage Test



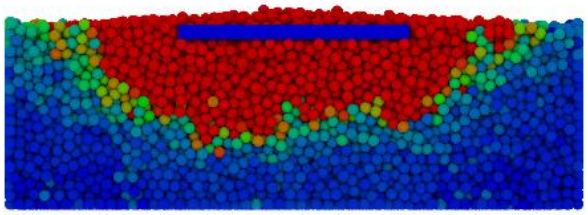
Direct Shear Test

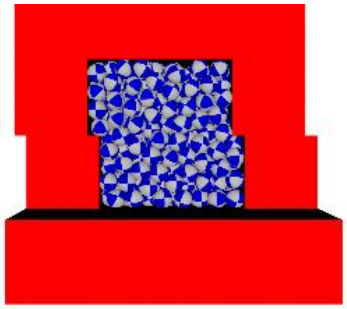


Single Wheel Test

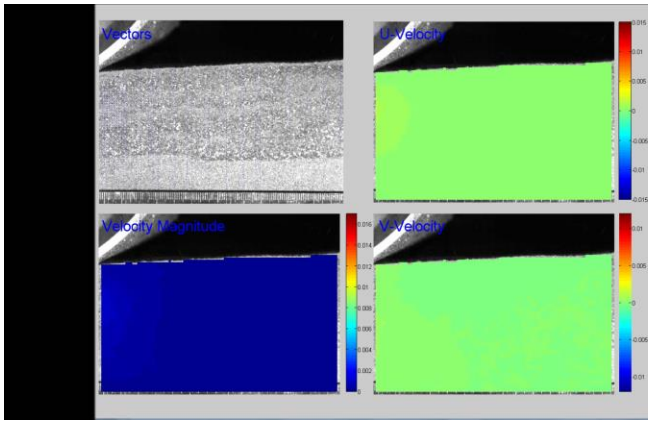


Simulations





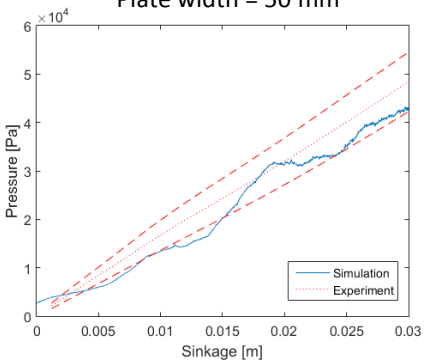
Particle Image Velocimetry



Validation of Theory: Scale Test Results

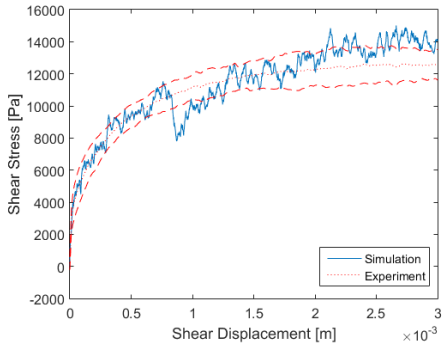
Pressure – Sinkage Test

Plate width = 50 mm

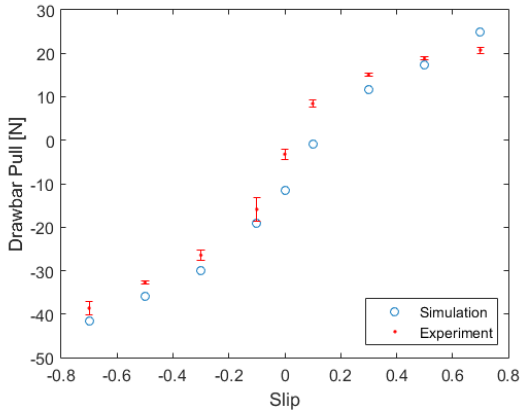


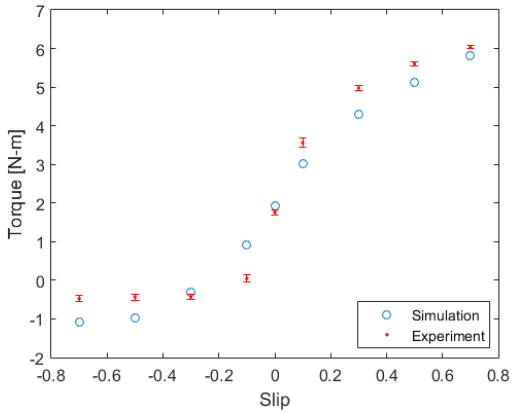
Direct Shear Test

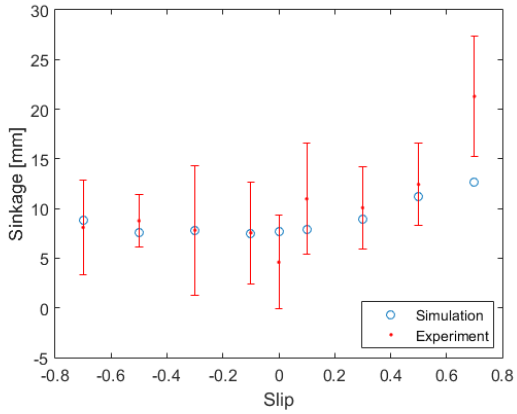
Normal load = 16 kPa



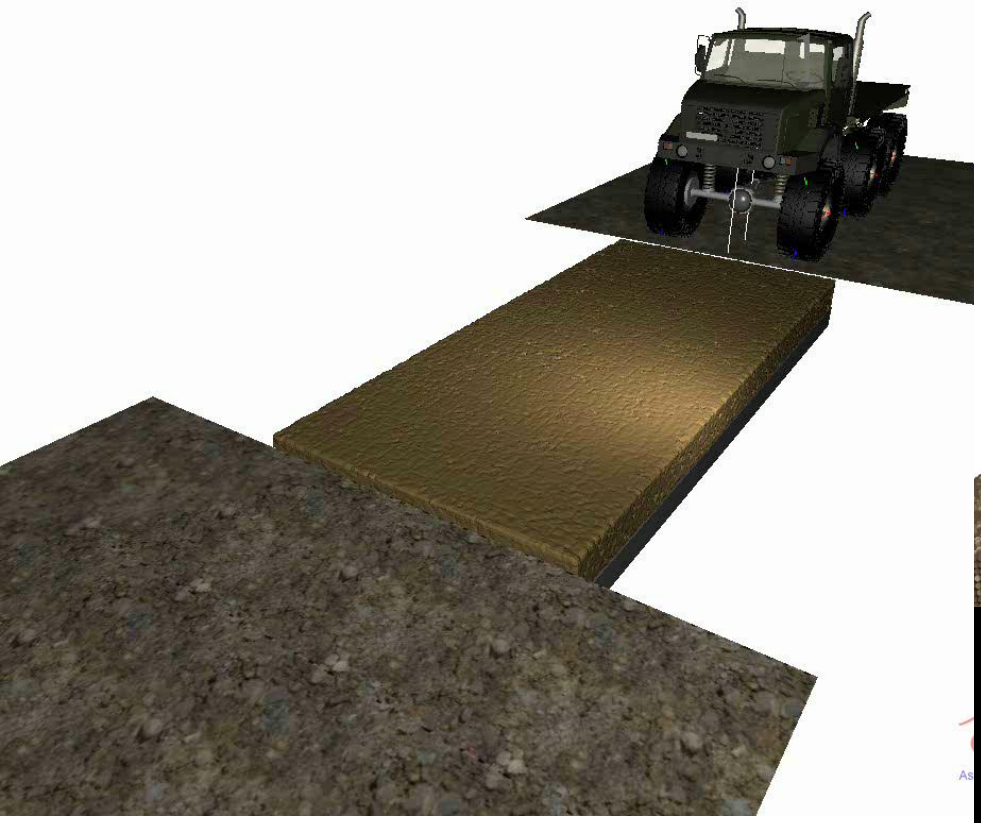
Single Wheel Test

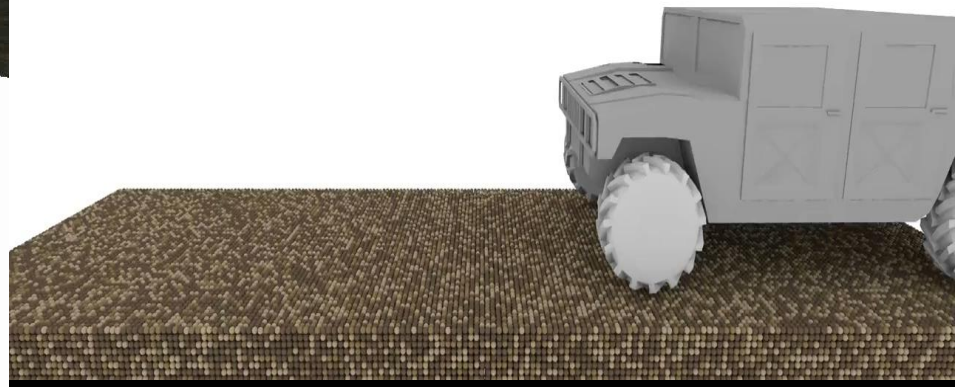


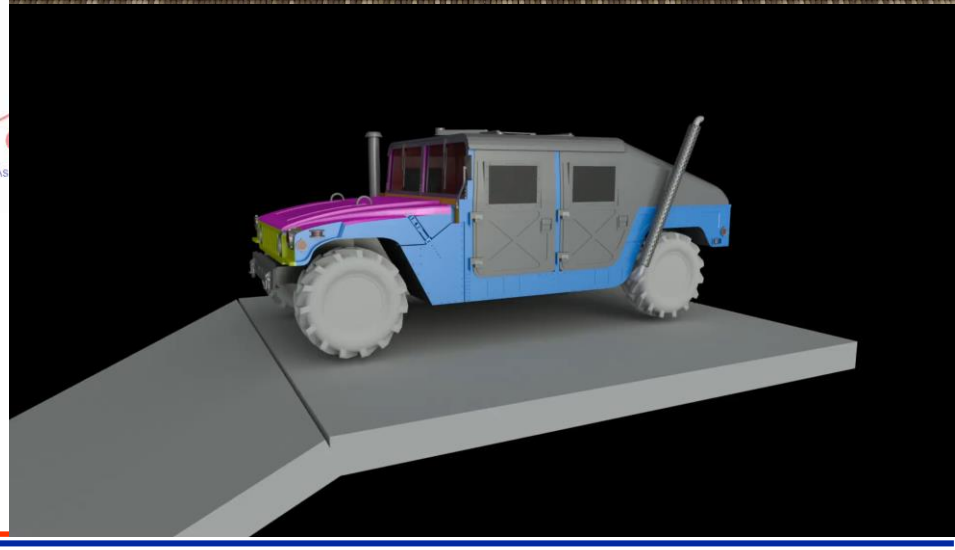




Full-Scale Demonstration: Physics-Based Mobility M&S





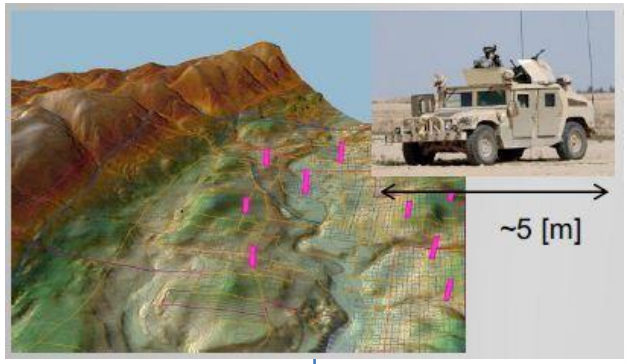


Computational Burden

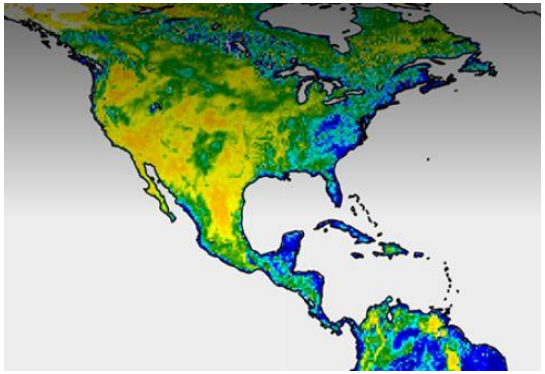
- **Hardware:** Cray XC40 32 cores
- **Software:** IVRESS; **Contact method:** DEM-P
- **Run time:** **14,000x slower than real time**
- **Model particle dia / Physical :** 30 mm **/** 0.002 mm
  = **15,000x bigger than real size**

Goal: NextGen NATO Reference Mobility Model

Terrain Elevation Map

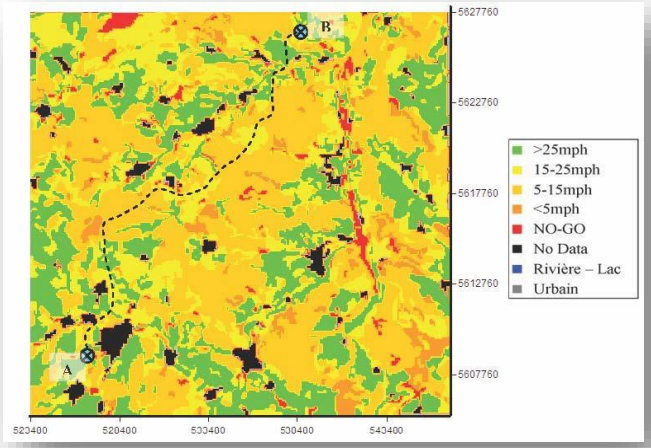


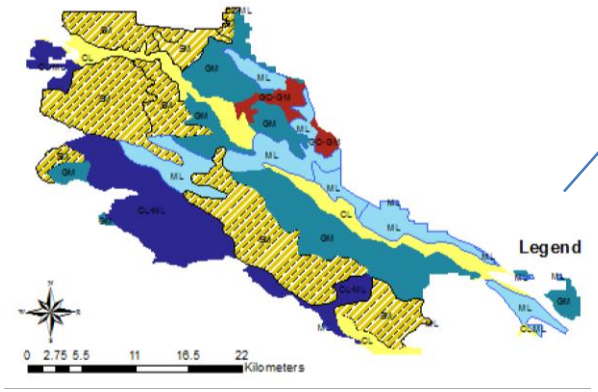
Soil Moisture Map



Physics-Based M&S

Mobility Go/NoGo Map





Soil Type

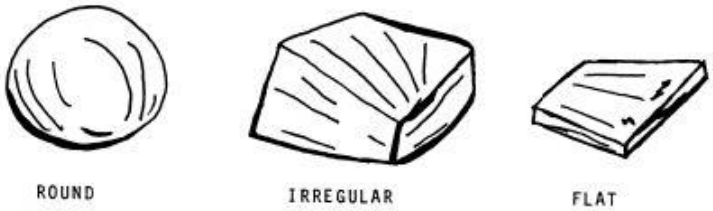
Qualitative — 1970

NRMM

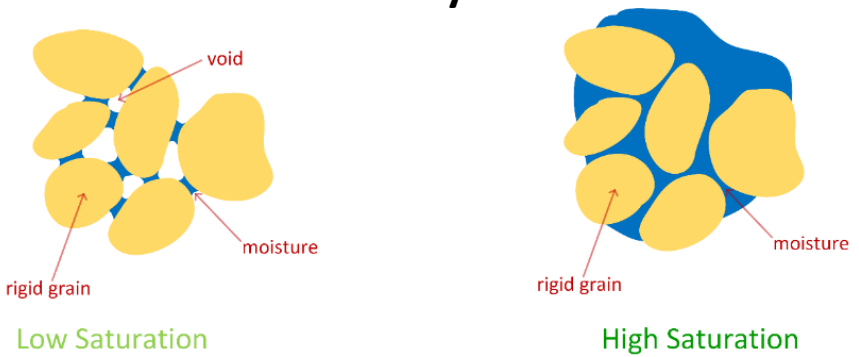
NG-NRMM — 2020

Challenging Nature of Terramechanics

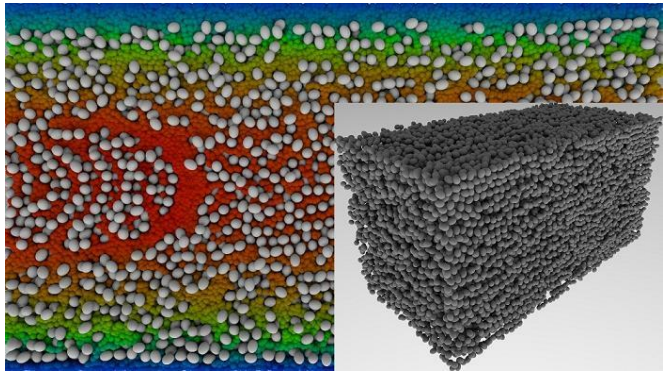
Heterogeneity



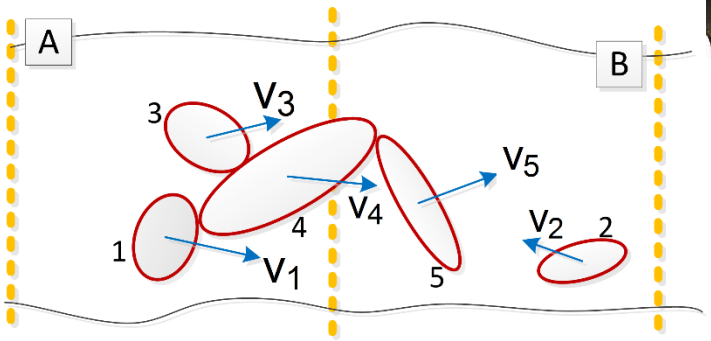
Multi-Physics



Scalability



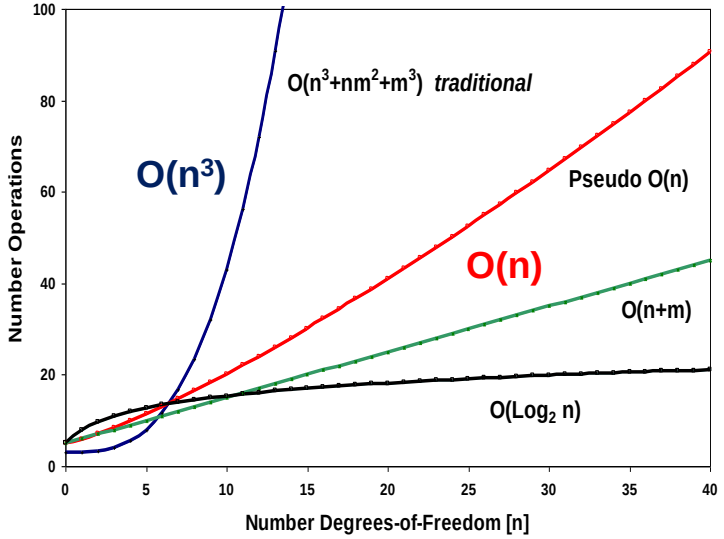
Dynamics



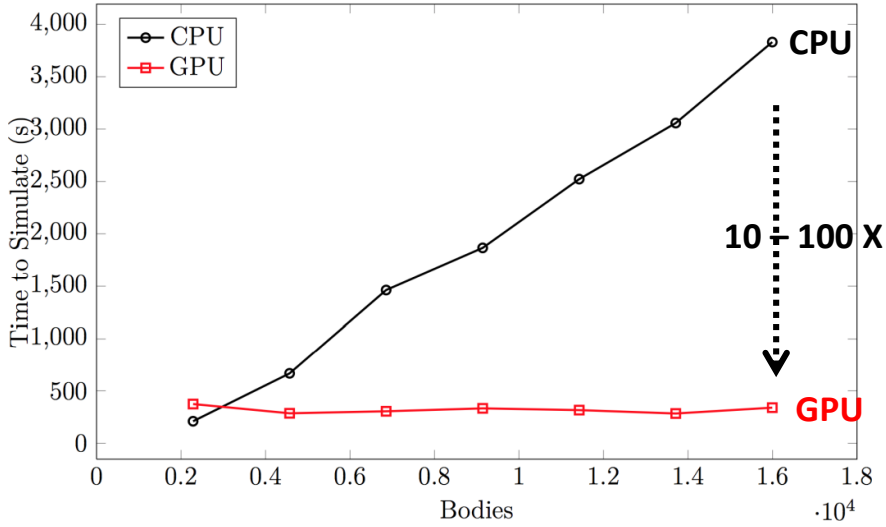
Multi-Scale

Performance Challenges: Algorithms and Hardware

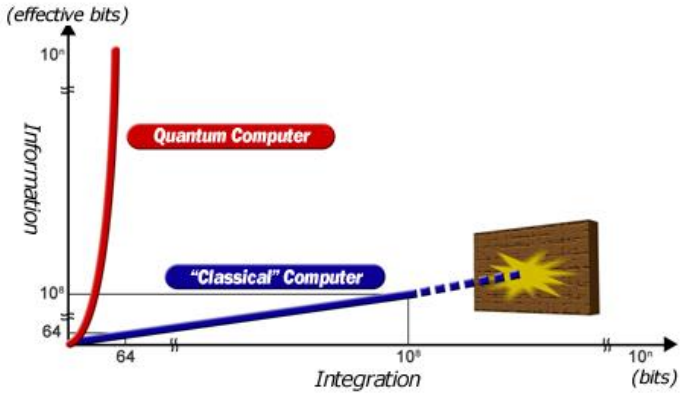
Algorithm Cost vs. Problem Size



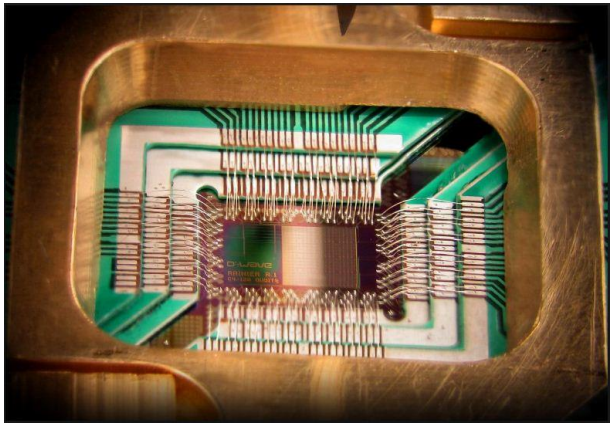
Compute Cost: CPU vs. GPU



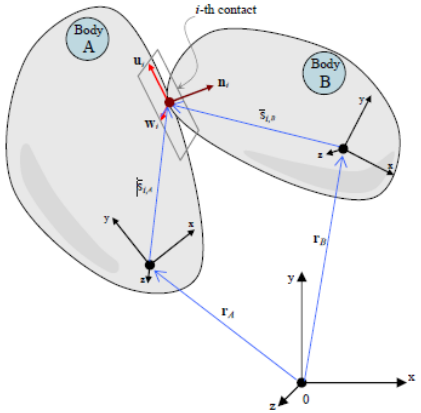
Massive Parallelization



Quantum Computing



Physics of Terramechanics and Quantum Computing



$$\dot{\mathbf{q}} = \mathbf{L}(\mathbf{q})\mathbf{v}$$

$$\mathbf{M}(\mathbf{q})\dot{\mathbf{v}} = \mathbf{f}(t,\mathbf{q},\mathbf{v}) - \mathbf{g}_{\mathbf{q}}^{\mathrm{T}}(\mathbf{q},t)\lambda + \sum_{i\in\mathcal{A}(\mathbf{q},\delta)} \underbrace{\left(\hat{\gamma}_{i,n}\,\mathbf{D}_{i,n} + \hat{\gamma}_{i,u}\,\mathbf{D}_{i,u} + \hat{\gamma}_{i,w}\,\mathbf{D}_{i,w}\right)}$$

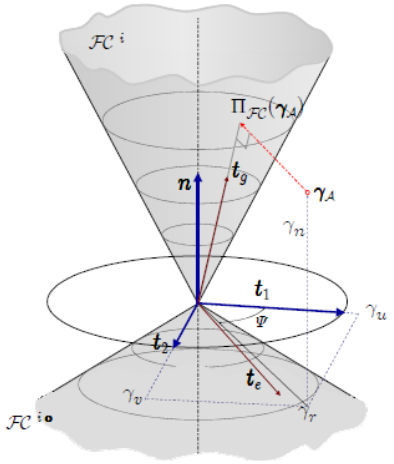
Frictional Contact Force

$$\mathbf{0} = \mathbf{g}(\mathbf{q},t)$$

$$i \in \mathcal{A}(\mathbf{q}(t),\delta) \quad : \quad \begin{cases} 0 \le \Phi_i(\mathbf{q}) \quad \perp \quad \hat{\gamma}_{i,n} \ge 0 \\ (\hat{\gamma}_{i,u}, \hat{\gamma}_{i,w}) = \underset{\sqrt{(\bar{\gamma}_u^i)^2+(\bar{\gamma}_w^i)^2} \le \mu_i \hat{\gamma}_{i,n}}{\operatorname{argmin}} \quad \mathbf{v}^T \cdot \left(\bar{\gamma}_u^i\,\mathbf{D}_{i,u} + \bar{\gamma}_w^i\,\mathbf{D}_{i,w}\right) \end{cases}$$

Complementarity Condition

Friction Dissipation Energy



Mobility Problem reduces to:
Quadratic **C**onstrained **C**ontinuous **O**ptimization Problem

Note that Quantum Computer can solve:
Quadratic **U**nconstrained **B**inary **O**ptimization Problem